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ELIMINATION OF CHROMATE CONVERSION COATINGS FROM ARMY TACTICAL VEHICLE MANUFACTURING PROCESSES

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ABSTRACT

Many United States Army light tactical vehicles are fabricated from armor-grade aluminum. Aluminum-hulled tactical vehicles are coated with the Army's standard Chemical Agent Resistant Coating (CARC) system. The CARC system includes chemical pretreatments, epoxy primers, and polyurethane topcoats. The MIL-C-5541 chromate conversion coating pretreatment process included in the CARC specification contains hazardous chromic acid. Chromic acid is a SARA Title III extremely hazardous substance and air emissions of the material will be regulated by the 1990 Clean Air Act Amendments. In 1989, Red River Army Depot (RRAD) staff investigated replacing the hazardous chromate conversion coating with a more environmentally acceptable production process. The Army Acquisition Pollution Prevention Support Office reviewed the RRAD results and tasked Ocean City Research Corporation (OCRC) to conduct a comprehensive coating performance assessment and develop appropriate non-chromate production process control documents. The evaluation program demonstrated that chromate conversion coatings may be eliminated from aluminum-hulled tactical vehicle painting operations without degrading overall coating system performance.

KEY WORDS: Military, corrosion, coatings, painting, chromates, conversion coatings, abrasive blasting.

1. INTRODUCTION

The United States Army currently manufactures light tactical vehicles (i.e. armored personnel carriers, rocket launchers, and self-propelled artillery) from armor-grade aluminum. The 5000 series (Al, Mg, Mn, Cr) aluminum alloys used to manufacture these vehicles are inherently corrosion resistant.(1) Thick aluminum (i.e greater than 1.0 inch [25.4 mm]) sections are typically welded together to form the tactical vehicle's hull.

The vehicle hull manufacturing process includes the application of Army's Chemical Agent Resistant Coating (CARC) system. The CARC system is a family of chemical pretreatments, epoxy primers, and polyurethane topcoats. CARC coatings are produced in specific camouflage colors and are designed not to absorb toxic chemical warfare agents. The CARC system materials and associated production

processes are described in MIL-C-53072, "Chemical Agent Resistant Coating (CARC) System Application Procedures and Quality Control Inspection."

All CARC system coatings are lead-free and many do not contain soluble chromates. However, the CARC approved chemical pretreatments for aluminum alloys do contain hexavalent chromium. Hexavalent chromium is a known human carcinogen, a SARA Title III extremely hazardous substance, and is included in the 1990 Clean Air Act Amendment's Hazardous Air Pollutants (HAPs) list.(2) Because many Army production/maintenance facilities have already adopted the lead and soluble chromate-free CARC coatings, these aluminum pretreatments are frequently the only hazardous chromate source in the paint shop.

Red River Army Depot (RRAD) re-manufactures aluminum-hulled tactical vehicles and applies the CARC coating system. The RRAD painting production process utilizes the following CARC materials:

- MIL-C-5541, "Chemical Conversion Coating for Aluminum and Aluminum Alloys."
- MIL-P-53022B, Type I, "Primer Epoxy, Corrosion Inhibiting, Lead and Chromate-Free."
- MIL-C-22750, "Coating, Epoxy-Polyamide."
- MIL-C-46168D, "Coating Aliphatic Polyurethane, Chemical Agent Resistant."

In 1989, RRAD personnel initiated an evaluation of alternative environmentally acceptable production processes that might be considered alternatives to the hazardous chromate conversion coating process. RRAD staff identified a two-stage abrasive blasting process as a viable alternative. Using this environmentally acceptable alternative production process as a replacement for chromate conversion coatings would reduce RRAD's yearly raw material costs by approximately $200,000 and could save approximately $3,000,000 in potential air emission control equipment upgrade costs. Even though adopting the environmentally acceptable alternative production process was economical, RRAD staff were required to generate additional coating system corrosion control performance data to obtain alternative production process approval.

In 1990, the Army Acquisition Pollution Prevention Support Office (AAPPSO) initiated a cooperative program with RRAD to generate the data required to obtain approval for replacing chromate conversion coatings with an environmentally acceptable alternative production process. The AAPPSO tasked Ocean City Research Corporation (OCRC) to conduct a comprehensive coating system corrosion control performance assessment and to use the performance assessment results to generate production process control documents for RRAD. The AAPPSO sponsored research program included a natural marine atmosphere exposure test of realistically complex, armor-grade aluminum specimens, numerous Army specific adhesion assessments, and a production process demonstration program.

2. TECHNICAL APPROACH

2.1 Realistic, Long-Term Performance Assessment Table I presents the coating system corrosion control performance evaluation program test matrix. The matrix presents both the chemical pretreatments and the alternative production processes used to produce test panels. The alternative production processes listed in Table I include the current RRAD production process, abrasive blasting with aluminum oxide media, and no pretreatment other than a solvent wipe. The current RRAD production process includes removal of old paint using AISI 303 stainless steel shot, hull rework, final abrasive blasting with garnet media, and primer application. Although RRAD currently uses only the MIL-P-53022 solvent-based epoxy primer, the test matrix also includes the MIL-P-53030 water-reducible epoxy primer. The water-reducible primer was included in the program to ensure results would be applicable to facilities that have already adopted this lower Volatile Organic Compound (VOC) content primer. All systems were topcoated with the two component MIL-C-46168 materia..

Two test panel types were used during the program. Complex test panels were used to evaluate coating system corrosion control performance in the natural marine atmosphere. Flat laboratory test panels were used in various adhesion and electrochemical evaluations.

Figure 1 shows a schematic of the complex marine atmosphere exposure test specimen. These complex specimens were fabricated by sectioning 1/4 inch (6.3 mm) thick armor-grade aluminum panels into two parts. These two parts were then single penetration fillet welded to produce an L-shaped panel. By creating the L-shape with a single penetration weld, a crevice was established that would present a "worst case" for localized corrosion. The panels also included a hole that would be inherently difficult to coat. The flat test specimens were fabricated from the same stock as the complex panels. Flat panel dimensions were nominally 4 x 9 inches (102 x 229 mm).

Both test panel types were pretreated and coated using the systems described in Table I. An Elcometer 300 dry film thickness measurement gauge was used to measure coating thicknesses. After inspection, the complex test panels had a 1/4 inch (6.3 mm) diameter hole cut through the coating and into the substrate aluminum. This intentional defect was added to create favorable conditions for substrate corrosion and coating undercutting.

The complex atmospheric exposure test panels were placed at OCRC's Sea Isle, NJ marine test site for two years. The panels were placed on racks facing south at an angle of 45 degrees and subject to daily seawater spray. During the two-year exposure period, substrate corrosion was evaluated in accordance with ASTM D 610 (modified to account for the alun...um substrate) and panel blistering was evaluated in accordance with ASTM D 714.3(4) Underfilm corrosion around the coating defect was also measured and recorded.

The laboratory test panels were evaluated for adhesion in the wet and dry conditions. The dry adhesion test (ASTM D 2197) used a weighted stylus to scrape the coating away from the aluminum substrate (greater stylus loads are associated with more adherent coatings). Wet adhesion was evaluated in accordance with Federal Standard 141C, Method 6301. The wet adhesion test used flat panels with two parallel scribes. After soaking the scribed panels in room temperature water for 24-hours, adhesive tape is applied over the scribed region. The tape was removed and the area of paint pulled away from the panel evaluated. Large areas of paint stuck to the adhesive tape indicated poor wet adhesion performance.

Additional laboratory tests were conducted to determine coating system resistance to the Army's powerful DS-2 chemical warfare cleaning agent. DS-2 is a strong alkali used in actual chemical warfare and during training. Because alkalies can strip paints, test panels with intentional defects were evaluated. Panels were soaked in a 140 F (60 C) DS-2 solution for 24-hours and then inspected for coating delamination or undercutting. Coating blistering was evaluated in accordance with ASTM D 714 guidelines.

2.2 Trial Production Process Implementation A production process control document was created for the modified, non-chromate based coating process. The document was generated in the current RRAD Depot Process Control Pamphlet (DPCP) format to ensure acceptance by shop personnel. This new DPCP, given the code number 0026 by RRAD staff, described the non-chromate aluminum hulled armored vehicle coating system production process and the required engineering controls. In addition, DPCP 0026 included a training material package to allow each worker, in a Total Quality Management (TQM) mode, to understand the overall process and contribute to successful coating application.

The modified, non-chromate production process was implemented on the test M577 over a four-week period. The M577 was tracked through each production phase and evaluated in accordance with MIL-C-53072 and DPCP 0026 guidelines. Parameters measured during the production process trial included; surface cleanliness, surface profile, coating wet film thickness, coating dry film thickness, and coating adhesion.

3. RESULTS & DISCUSSION

3.1 Realistic, Long-Term Performance Assessment Table II summarizes marine atmosphere test panel coating system corrosion control performance after two-years of testing. The coating systems listed in Table II correlate with those described in Table I. The ASTM B 610 and D 714 data show all panels maintained a 10 rating. The 10 rating signifies no substrate corrosion or coating blistering was apparent. The scribe undercutting data show that no panels exhibited undercutting. The qualitative weld crevice corrosion and coating failure (i.e. near the hole) data also show no degradation over the two-year period. These "real-world" test results prove that CARC coated, armor-grade aluminum test panels prepared with and without the

chromate conversion exhibit equivalent, excellent marine atmosphere corrosion control performance.

Figure 2 shows laboratory ASTM D 2197 scratch adhesion test results. Given that lower scratch failure loads are associated with less adherent coatings, the Figure 2 data show that specimens with the chromate conversion pretreatment were less adherent than panels prepared with the phosphoric acid rinse or those prepared with two primer coats. The specimens prepared with the RRAD standard abrasive blasting technique performed less effectively than those with the chromate. However, panels prepared using the phosphoric acid rinse process outperformed the chromated specimens. The only systems that performed poorly in the scratch adhesion test were those with no surface preparation other than a solvent wipe. These systems scratched at loads that were significantly lower than those for better performing systems. Figure 2 data show that chromate conversion coatings are one of many alternative, acceptable surface pretreatments that provide superior adhesion to unprepared (solvent wiped) surfaces.

The wet adhesion test results indicated that only the specimens with no surface treatment (i.e. solvent wipe) produced failures. All solvent wipe test panels exhibited significant wet adhesion failures. These findings tend to confirm the trends observed in the Figure 2 data.

Figure 3 shows the laboratory DS-2 test data. The Figure 3 ASTM D 714 blistering data include both a numerical rating and a qualitative description of blister density. Given that higher numerical ratings are associated with smaller blisters, Figure 3 data show that chromate conversion coated test specimens had larger and more frequent blisters than all but the panels prepared with just a solvent wipe. These Figure 3 data show that panels prepared with the chromate conversion coating were more susceptible to DS-2 induced blistering than virtually any other pretreatment.

Overall, these realistic coating system corrosion control and laboratory performance tests demonstrate that chromate conversion coatings are only one of many alternative surface pretreatments that offer adequate overall performance. These results demonstrated that chromate conversion coatings could be replaced by mechanical surface preparation. Based on these findings, AAPPSO staff tasked OCRC to develop a non-chromate production process control technical data package and conduct an implementation trial.

3.2 Trial Production Process Implementation The production process technical data package was developed by modifying existing RRAD production processes to address research findings. Whenever possible, current RRAD equipment and processes were used to simplify transition from the chromate to the non-chromate surface pretreatment production process. The key issues identified during the technical data package development program were that an adequate surface profile was essential to overall performance and that a high degree of surface cleanliness would help ensure effective coating adhesion.

Generating a consistent and adequate surface profile was complicated by the current RRAD abrasive blasting processes. RRAD currently removes coatings using an 303 stainless steel centrifugal shot blast cabinet. This device produces a heavy surface profile of between 2.8 and 3.5 mils (0.071 to 0.089 mm). After this coating removal operation, vehicles are reworked, welded, and refitted. To remove the oxides and contaminants deposited on the hulls during these various manufacturing operations, the vehicles are blasted with 20 mil (0.5 mm) garnet media just before final painting. The fine garnet media actually reduces the surface profile.

Table III presents final profile data from four standard production aluminum hulls. As shown, average profiles varied considerably between 1.60 mils (0.04 mm) and 3.72 mils (0.09 mm). In addition, the profiles varied on the individual vehicles. Because test data indicated that heavier surface profiles would improve adhesion, the production process control package was developed to ensure workers obtained a minimum profile of 2.0 mils (0.05 mm).

The surface cleanliness analysis proved vital to overall program success. Many RRAD production processes contaminated the hull surfaces with lubricants and waxes that were extremely difficult to remove. If these contaminants remained on the hull in the paint shop, the final coatings would exhibit virtually no adhesion. To address surface cleanliness, the process control data package includes both training and quality assurance provisions. Workers in the final garnet blasting area were trained to identify the oil/wax contaminated regions and effectively remove the materials. Workers in the prepaint preparation shop were provided with a simple "water break" test to verify surface cleanliness before painting. Thus, the production process controls maintain an internal verification of surface cleanliness.

Figure 4 shows the final mechanical surface preparation production process flow chart. As shown, the process includes both surface profile and cleanliness verification.

Figure 5 shows a similar flow chart for the primer application process. In the past, an initial stage of this flow chart would have been chromate conversion coating application. As shown, the proposed production process does not use hazardous chromate materials.

The Figure 4 and 5 production processes were used as a basis for trial coating application to an M577 vehicle in March 1993. The vehicle was successfully coated and inspected by RRAD quality assurance personnel. All inspections indicated the M577 without the chromate conversion coating was indistinguishable from a standard production vehicle.

Based on the successful implementation trial, RRAD staff are awaiting final Army approval for chromate conversion coating elimination. Upon obtaining final Army approval, a comprehensive training program will be initiated to ensure workers

understand the chromate elimination process and the importance of effective process control.

4. CONCLUSIONS

The following are the program conclusions:

1. Natural marine atmosphere exposure test performance data, collected over two-years, indicate that complex armor-grade aluminum panels prepared both with and without the chromate conversion pretreatment did not experience any coating failures or substrate corrosion.

2. Scratch adhesion test data indicate that the chromate conversion coating is one of many acceptable pretreatment processes. Panels pretreated with abrasive blasting followed and a phosphoric acid solution offered the most effective scratch adhesion resistance. Wet adhesion test results indicate that only panels without any form of pretreatment experienced failures.

3. DS-2 blister test data suggest chromate conversion coatings were one of the least effective surface pretreatments. Panels prepared by abrasive blasting with aluminum oxide offered significantly more resistance to blistering than those prepared with the chromate conversion coatings.

4. Production process controls that emphasize surface profile and cleanliness are essential to effectively applying CARC coatings to non-chromate conversion coated aluminum armored vehicle hulls. When implemented, effective production process controls allow aluminum-hulled armored vehicles to be coated without the use of any hazardous chromate bearing materials.

5. REFERENCES

1. Metals Handbook, Ninth Edition, Volume 13, Corrosion, ASM International, 1987, page 586.

2. 1990 Clean Air Act Amendments, Title III (Section 112 in Title I), Hazardous Air Pollutants.

3. ASTM D 610, "Method for Evaluating Degress of Rust on Painted Steel Surfaces"

4. ASTM D 714, "Method for Evaluating Degree of Blistering of Paints"

5. ASTM D 2197, "Test Method for Adhesion of Organic Coatings by Scrape Adhesion Tester"

TABLE I
CHROMATE ELIMINATION PROGRAM TEST MATRIX

SYSTEM #	NUMBER OF PANELS	ABRASIVE BLAST	PRETREATMENT TYPE	PRIMER TYPE	TOPCOAT
1	14	RRAD	CHROMATE	MIL-P-53030	MIL-C-46168
2	14			MIL-P-53022	
3	14		PHOSPHORIC	MIL-P-53030	
4	14			MIL-P-53022	
5	14		NONE	MIL-P-53030	
6	14			MIL-P-53022	
7	14			MIL-P-53030 (2 COATS)	
8	14			MIL-C-53022 (2 COATS)	
9	14	ALUMINUM OXIDE		MIL-P-53030	
10	14			MIL-P-53022	
11	14			MIL-P-53030 (2 COATS)	
12	14			MIL-P-53022 (2 COATS)	
13	14	NONE	SOLVENT WIPE	ML-P-53030	

Aluminum=Alumir um Oxide [ast, 2 - 3 mils profile.
RRAD=Stainless Steel Shot a. d River Sand (garnet) as per SOP-71.
Chromate-Chromate Conversion Coating, MIL-C-5541.
Phosphoric-Phosphoric Acid Wash, MIL-C-5541.
MIL-P-53022=Solvent-based Epoxy.
MIL-P-53030=Water Reducible Epoxy.

Table II
Two-Year Marine Atmosphere Exposure Test Results

System Number	ASTM D 610 Rating (avg.)	ASTM D714	Scribe Cut-back (avg.)	Weld Area Corrosion	Hole Corrosion
1	10	0	0	None	None
2	10	10	0	None	None
3	10	10	0	None	None
4	10	10	0	None	None
5	10	10	0	none	None
6	10	10	0	None	None
7	10	10	0	None	None
8	10	10	0	None	None
9	10	10	0	None	None
10	10	10	0	None	None
11	10	10	0	None	None
12	10	10	0	None	None
13	10	10	0	None	None

Table III
RRAD Surface Profile Data

Vehicle	Average Profile (mils/mm)	Maximum Profile (mils/mm)	Minimum Profile (mils/mm)
M113AT34	1.60/0.04	2.20/0.06	1.20/0.03
M112AT24	2.56/0.06	3.00/0.08	2.00/0.05
M577LH24	2.76/0.07	3.00/0.08	2.50/0.06
M577LH17	3.72/0.09	4.00/0.10	3.00/0.08

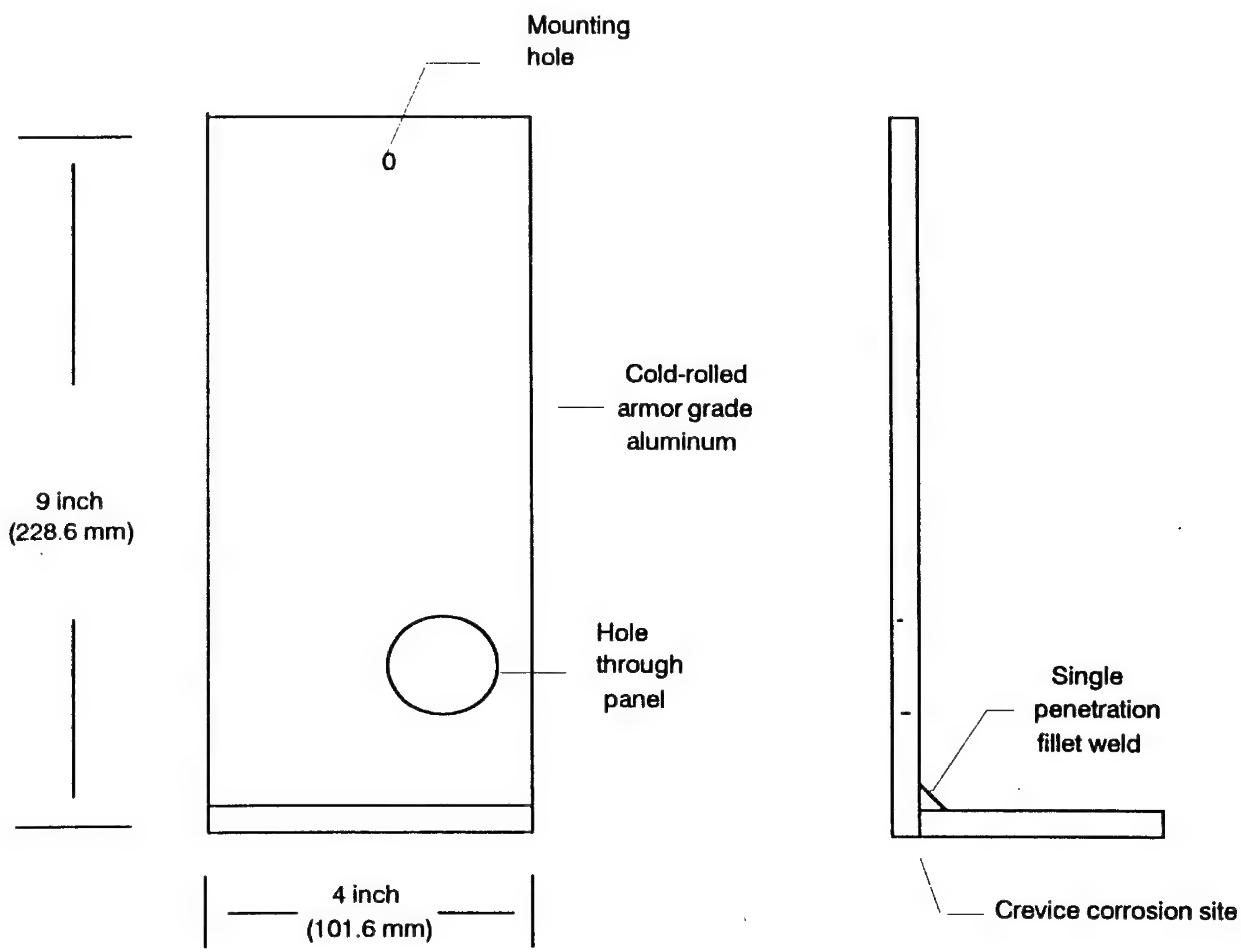


Figure 1 Marine Atmosphere Exposure Test Panel.

Figure 2 Scratch Adhesion Data

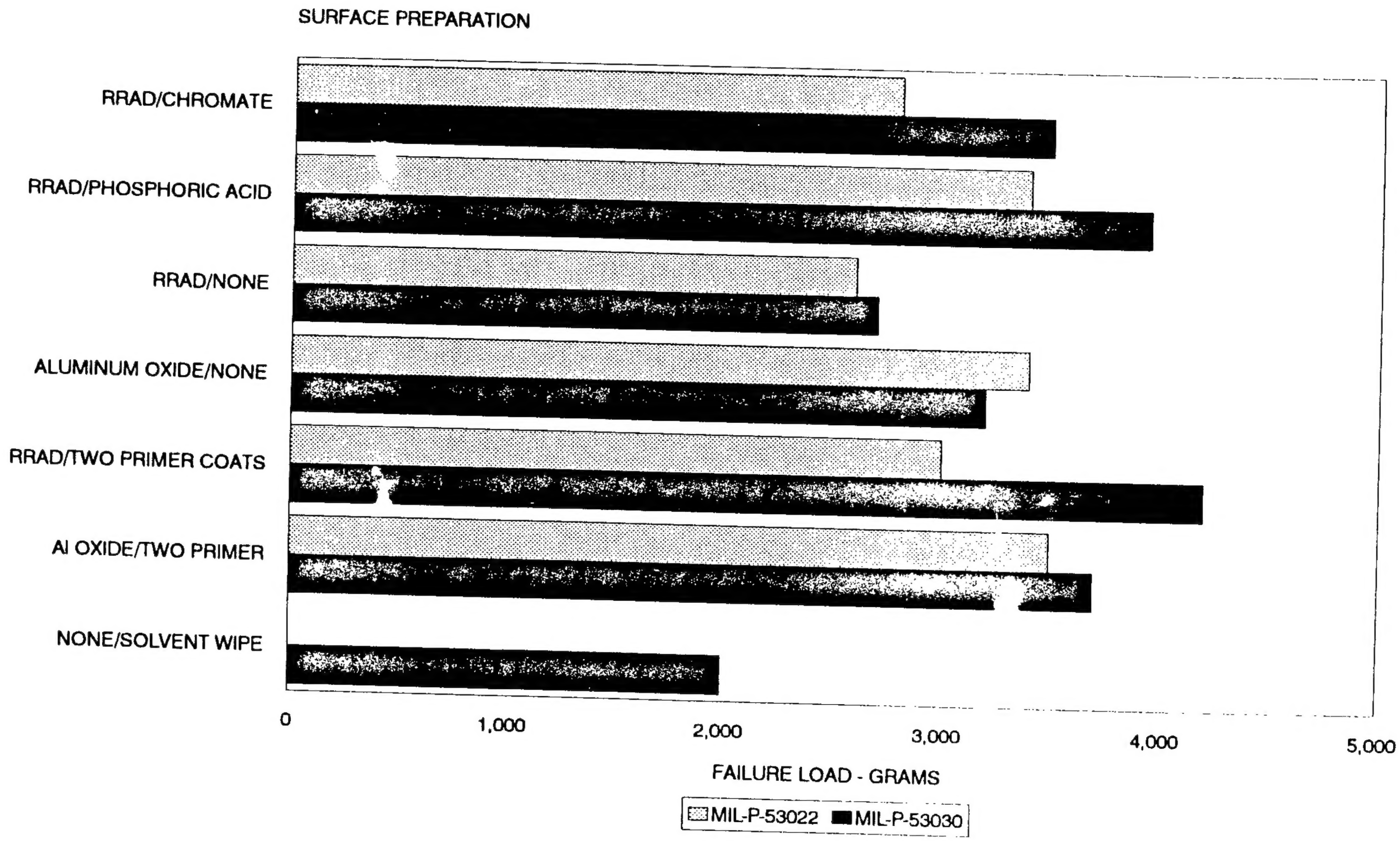
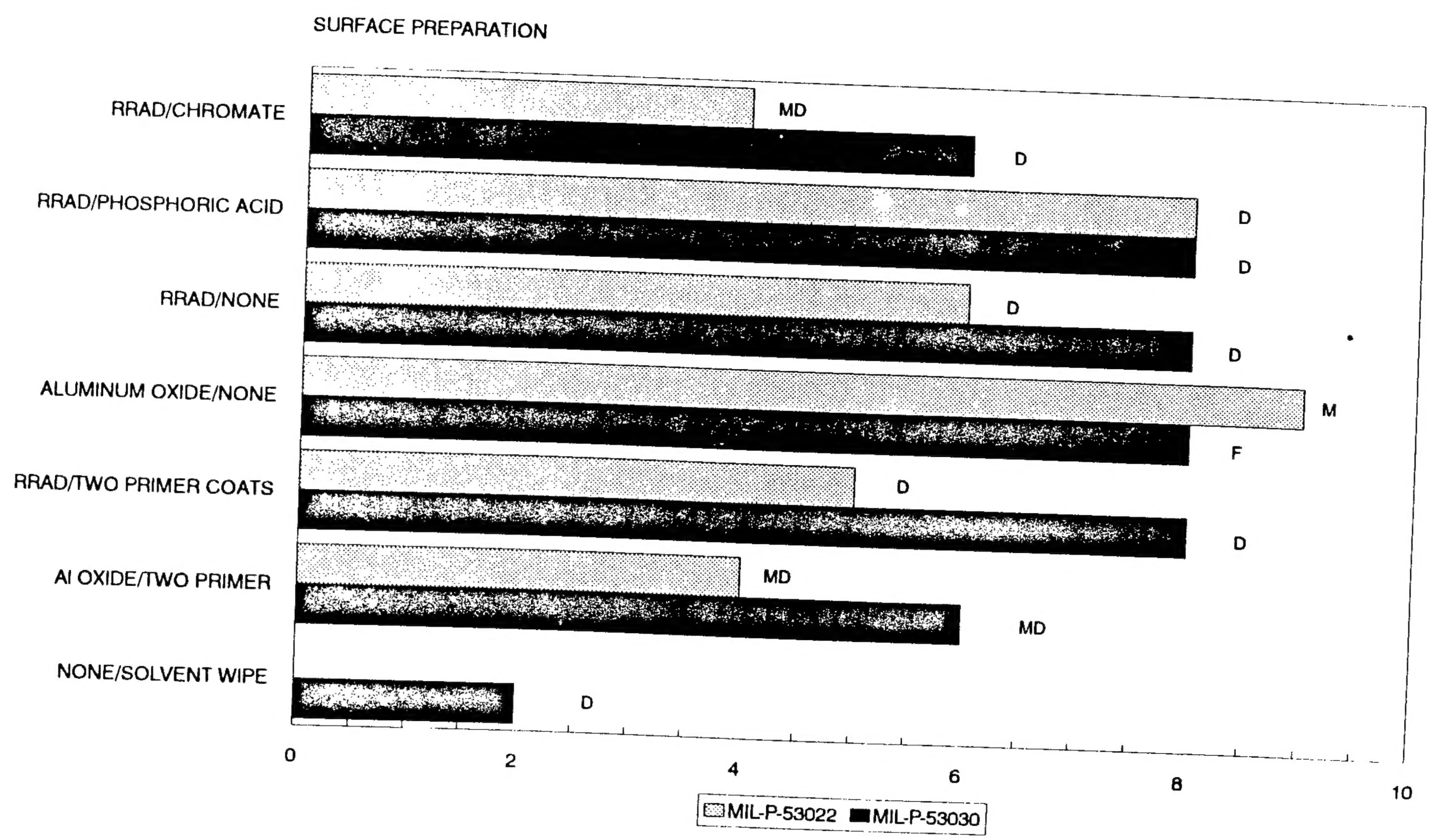


Figure 3 DS-2 Blister Test Data



Blister Frequency. F=Few, MD=Medium Density, D=Dense

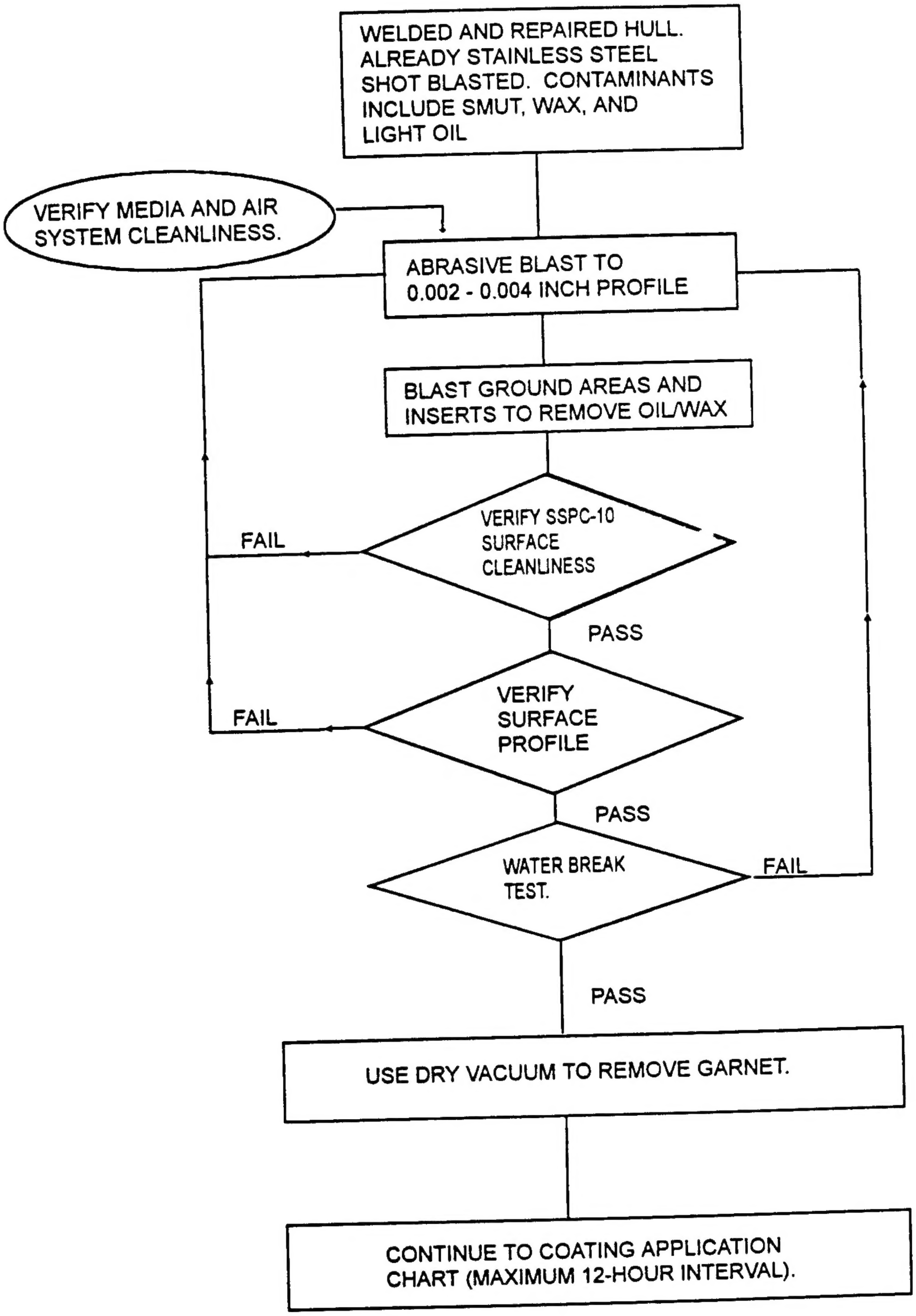


Figure 4 Dry Aluminum Hull Blasting Process

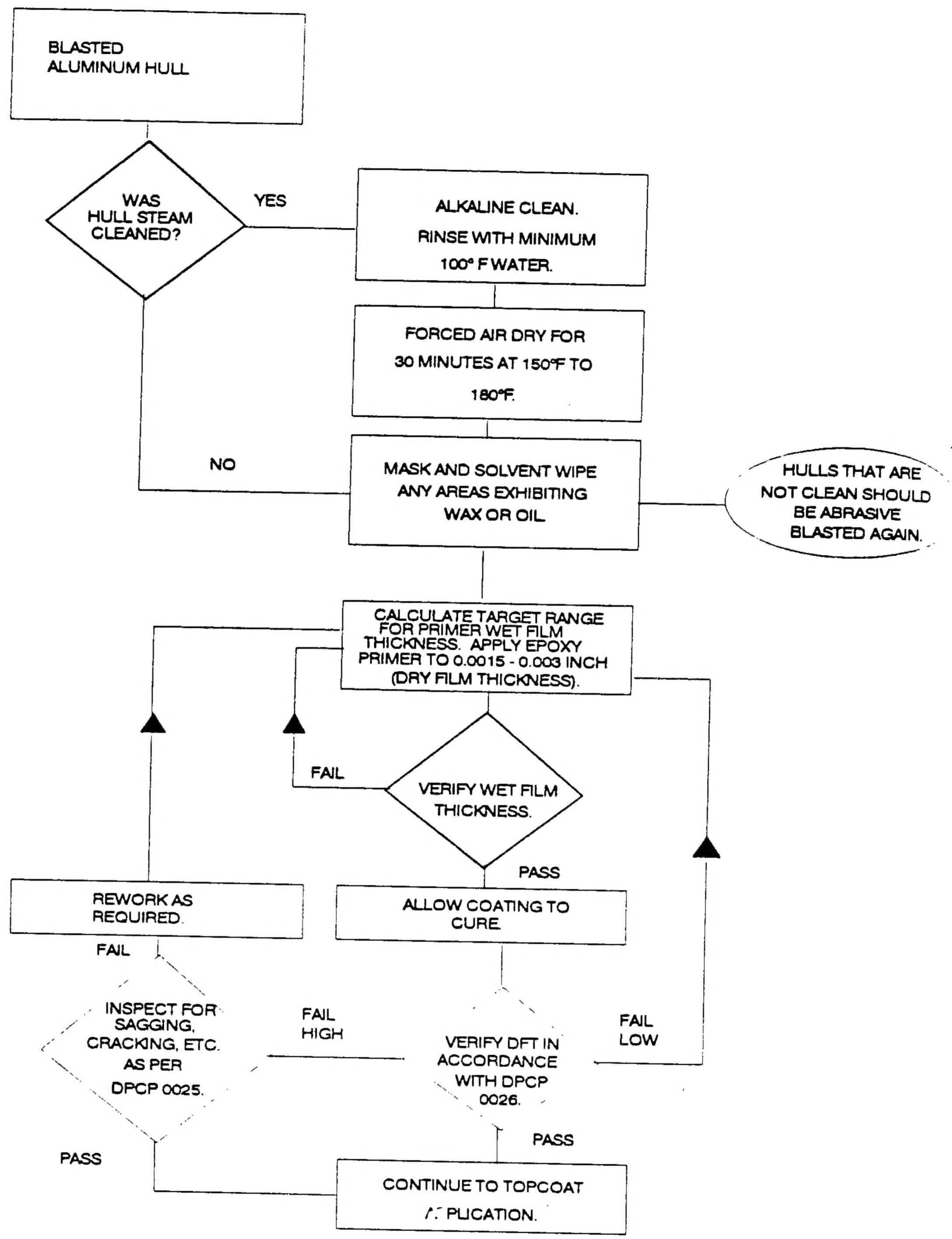


Figure 5 Primer Application Process